Control and automation of Asynchronous motor using Fuzzy logic

Mohammed BOUZIDI[1], Abdelkader HARROUZ[2], Smail MANSOURI[2]

[1]*Department of Science and Technology, Institute of Science and Technology, University Center of Tamanrasset, Algeria*

[2]*Department of Hydrocarbons and Renewable Energies, Laboratory of Sustainable Development and Computer Science (L.D.D.I), Ahmed Draia University – Adrar, Algeria.*

[*]Corresponding author Email: mohbouzidi81@yahoo.fr

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ABSTRACT

In this paper, we present the design of an intelligent approach based on adaptive fuzzy logic applied to the speed controller for a three-phase asynchronous motor. In this way, the main objective of applying the technique of fuzzy logic for the control of the speed of rotation with the variation of the resistance of the rotor, also to obtain a variable of high performance of the speed drive system and the stability of the electromechanical system in the region at high and low speed.

I. Introduction

In the control of non-linear systems or systems with non constant parameters, conventional control laws may be insufficient as they are not robust especially when the requirements on accuracy and other dynamic characteristics of the systems are strict. We must use control laws that are insensitive to parameter variations, disturbances and non-linearity. For this purpose, several tools are proposed in the literature, of which we quote the fuzzy logic [1-3].

Since the work of Mamdani (1974), the area of control by fuzzy logic has become very important, thanks to this ability to process certain information. The fuzzy logic control algorithm is made up of a set of decision rules; it can be considered a non-mathematical control algorithm unlike conventional control algorithms. [1], [4-5].

A Harrouz et al [6], present a simulation of synchronous inductor machines and applied the vector control to the machine for normal mode and flow control, which is based on the classical PI controllers.

In this paper, the performance of the fuzzy logic adjustment of the Asynchronous Autopilot Machine (MAS) powered by voltage with direct flow orientation is analyzed by numerical simulation. We start with the presentation of the model of the Asynchronous machine in the PARK marker for vector control. After this, a fuzzy logic control is developed. The control is performed with fuzzy logic controller (RLF). We give a brief overview of the voltage inverter. Finally, we simulate the real-time operation of the UPS-MAS-Control assembly. The results obtained with the proposed RLF algorithm and the disturbance robustness tests are analyzed.

II. Indirect Vector Control

II.1 Principle

For vector control we use the MAS model in the marker (d, q). Thanks to a representation in a marker linked to the rotating field whose axis d is aligned with the vector rotoric flux (Φrd=Φr) and (Φrq=0) therefore.

In the case of a voltage control it is necessary to generate the reference voltages vSd* and vSq*, which are converted into statoric quantities by a reverse Park transformation, will be able to control the engine and impose the desired flow and torque. The representation of the MAS is given by the following expressions:

$$\frac{di_{Sd}}{dt} = -\left(\frac{1}{\sigma.T_S} + \frac{1}{T_R}.\frac{1-\sigma}{\sigma}\right).i_{Sd} + \omega_S.i_{Sq} + \left(\frac{1-\sigma}{\sigma}.\frac{1}{M_{SR}.T_R}\right).\phi_R + \frac{1}{\sigma.L_S}.v_{Sd} \quad (1)$$

$$\frac{di_{Sq}}{dt} = -\omega_S.i_{Sd} - \left(\frac{1}{\sigma.T_S} + \frac{1}{T_R}.\frac{1-\sigma}{\sigma}\right).i_{Sq} - \left(\frac{1-\sigma}{\sigma}.\frac{1}{M_{SR}}.\omega\right).\phi_R + \frac{1}{\sigma.L_S}.v_{Sq} \quad (2)$$

$$\frac{d\phi_{Rd}}{dt} = \frac{M_{SR}}{T_R}.i_{Sd} - \frac{1}{T_R}.\phi_{Rd} \quad (3)$$

$$0 = \frac{M_{SR}}{T_R}.i_{Sq} - \omega_{gl}.\phi_{Rd} \quad (4)$$

Hence the expressions of statoric tensions can be drawn [7]:

$$v_{Sd} = \left(R_S + R_R.\frac{M_{SR}^2}{L_R^2}\right).i_{Sd} + \sigma.L_S.\frac{di_{Sd}}{dt} - \omega_S.\sigma.L_S.i_{Sq} - \frac{M_{SR}}{L_R^2}.R_R.\phi_R \quad (5)$$

$$v_{Sq} = \left(R_S + R_R.\frac{M_{SR}^2}{L_R^2}\right).i_{Sq} + \sigma.L_S.\frac{di_{Sq}}{dt} + \omega_S.\sigma\sigma._S.i_{Sd} + \frac{M_{SR}}{L_R}.\omega\omega._R \quad (6)$$

The direct and quadratic voltages vSd and vSq are then reconstructed from the two variables vSd1 and vSq1 and the compensation terms and , as expressed by the relations (7)and (8).

$$v_{Sd} = v_{Sd1} - \tilde{e}_{Sd} \quad (7)$$

$$v_{Sq} = v_{Sq1} - \tilde{e}_{Sq} \quad (8)$$

Using this decoupling technique shown in Figure1, if the compensation is correct (i.e., if: and), the action on one of the inputs will not cause any variation on the other output.

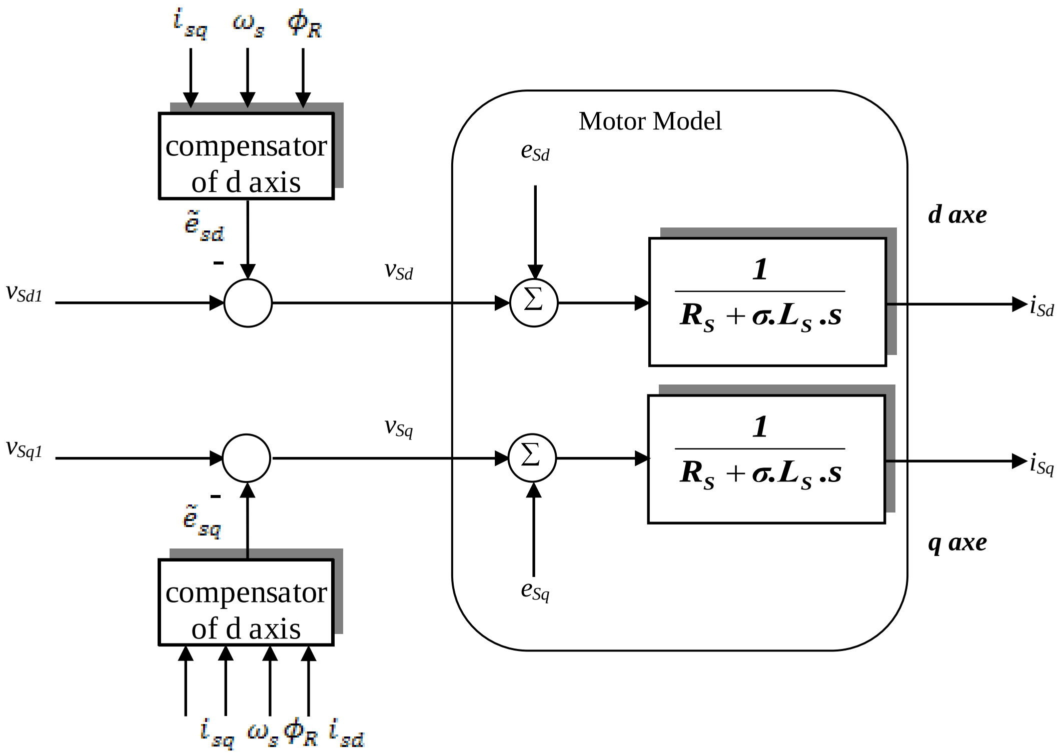

Figure 1. Principle of decoupling by static compensation

The figure 2 shows an example of an indirect vector control structure for regulating the speed of a three-phase asynchronous motor.

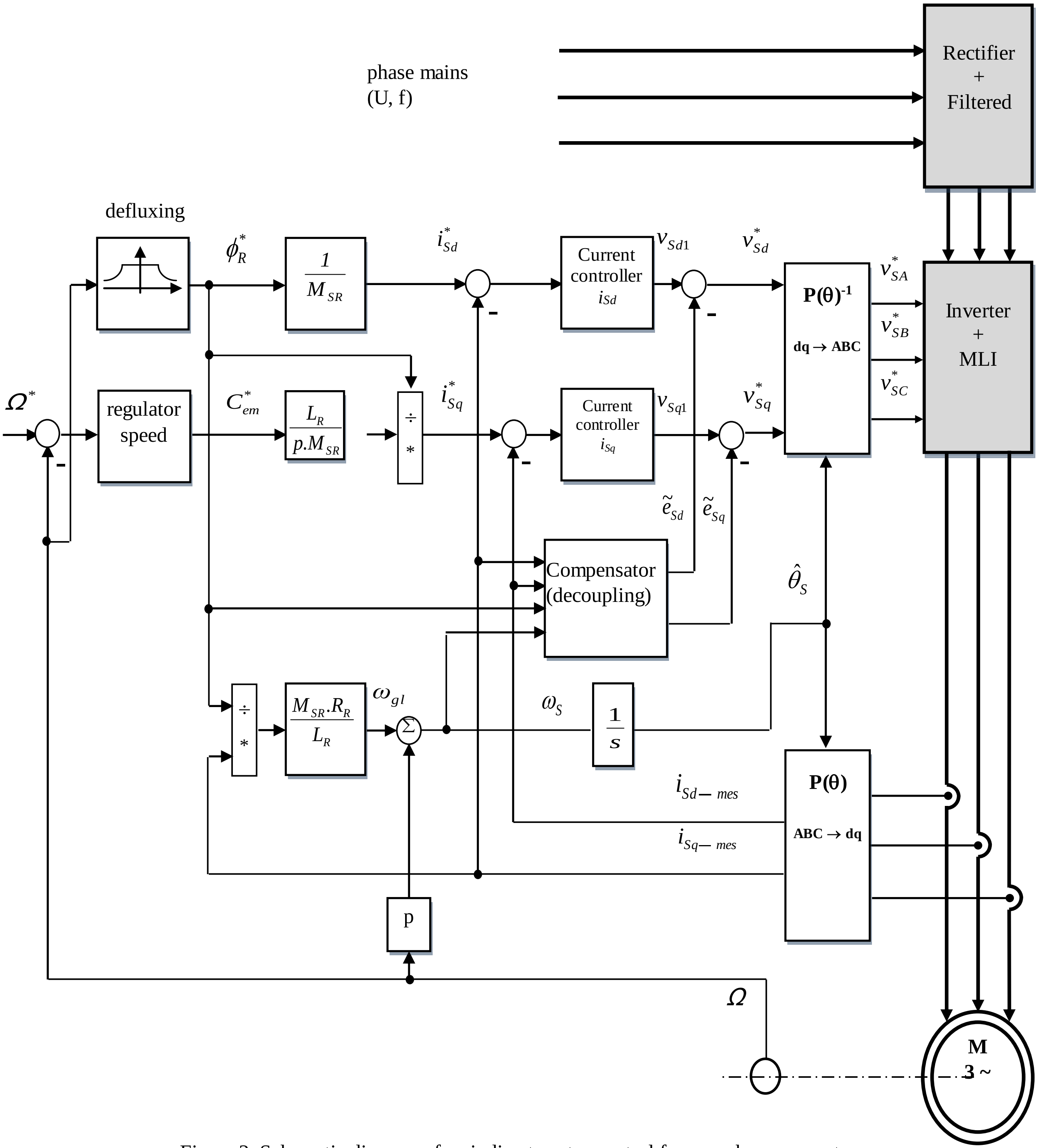

Figure 2. Schematic diagram of an indirect vector control for asynchronous motor

II.2 Numerical Application

The structure of the control showing a cascade regulation, we dimensioned the current regulators so that they are faster than the speed regulator located in the external loop.
The PI speed regulator parameters were determined in order to obtain responses characterized by similar rise times when they are subjected to a speed step and in the absence of load.
The parameters were calculated using the dimensioning relationships defined above, then adjusted by simulation using the trial-and-error method.

We opted for a flux value of 0.85Wb, for a rise time of tm ≈ 50 ms for the speed response, and finally for the current regulators a response time fixed at a value of tr5% = 2 ms .
The adjustment parameters obtained are given in table 1:

Table 1. Parameter values of the different regulators

Regulators	Proportional coefficient	Integral coefficient
PI type speed	K_{pw} = 0.775	K_{iw} = 4.33
of current (i_{sd} et i_{sq})	$K_{pd} = K_{iq}$ = 24.05	$K_{id} = K_{iq}$ = 26775

II.3 Simulation Results

The results obtained for the various simulation tests carried out, for the asynchronous motor and the inverter equipped with the indirect vector control developed in this chapter, are shown respectively in the figures:

- Figures 3 and 4 for the continuation tests,
- Figures 5 and 6 for the regulation tests,
- Figure 7 and 8 for the influence of the variations in the moment of inertia,
- Figure 9 and 10 for the influence of variations in rotor resistance.

II.4 Interpretations

With regard to the simulation results, we can notice the goods made from vector control provided with the PI type speed regulation structure.

For the different profiles, the rotation speed follows its reference relatively well with a low tracking error during the transient phases and canceling out in steady state. There is an excellent orientation of the rotor flow on the direct axis.

This affects the electromagnetic torque, which perfectly follows the reference torque, representing the control law generated by the controller.

The current and torque peaks at start-up are well controlled and lower than they were for the process alone. During the changes in the set points, and in particular during the rotation reversal, the change in the direction of the torque does not degrade the orientation of the flow.

There is good sensitivity to load disturbances, with a relatively short rejection time. Also when the load torque is applied or removed, the regulator reacts instantly to the reference electromagnetic torque, in order to produce an acceleration or a deceleration as the case may be, and thus reach the set speed. We also note the existence of an electromagnetic couple at zero speed.

The variations in the moment of inertia have very little influence on the orientation of the flow, however the speed is affected, both during the pursuit and during the application of disturbances.
On the other hand, variations in rotor resistance influence not only the speed, but also the orientation of the flux during the transient phases.

The advantages of vector control are numerous, we can cite among others: an excellent speed response in a wide adjustment range, with a low tracking error, a satisfactory control of the torque and stator current.

However, the Achilles heel of this technique is its low robustness in the face of variations in engine parameters and operating conditions, particularly with the use of conventional controllers.

Finally, we have developed the model of an indirect vector control in the MATLAB / SIMULINK environment in order to carry out a series of simulations, in order to assess the performance of this technique in tracking, regulation and in the face of parametric variations.
Thus, the PI controller was synthesized, then compared for a step speed reference and the application of a load torque. The PI type controller having shown superior performance to its counterpart, we selected it for the purpose of comparison with the control strategies defined in the following steps.

❖ Pursuit tests

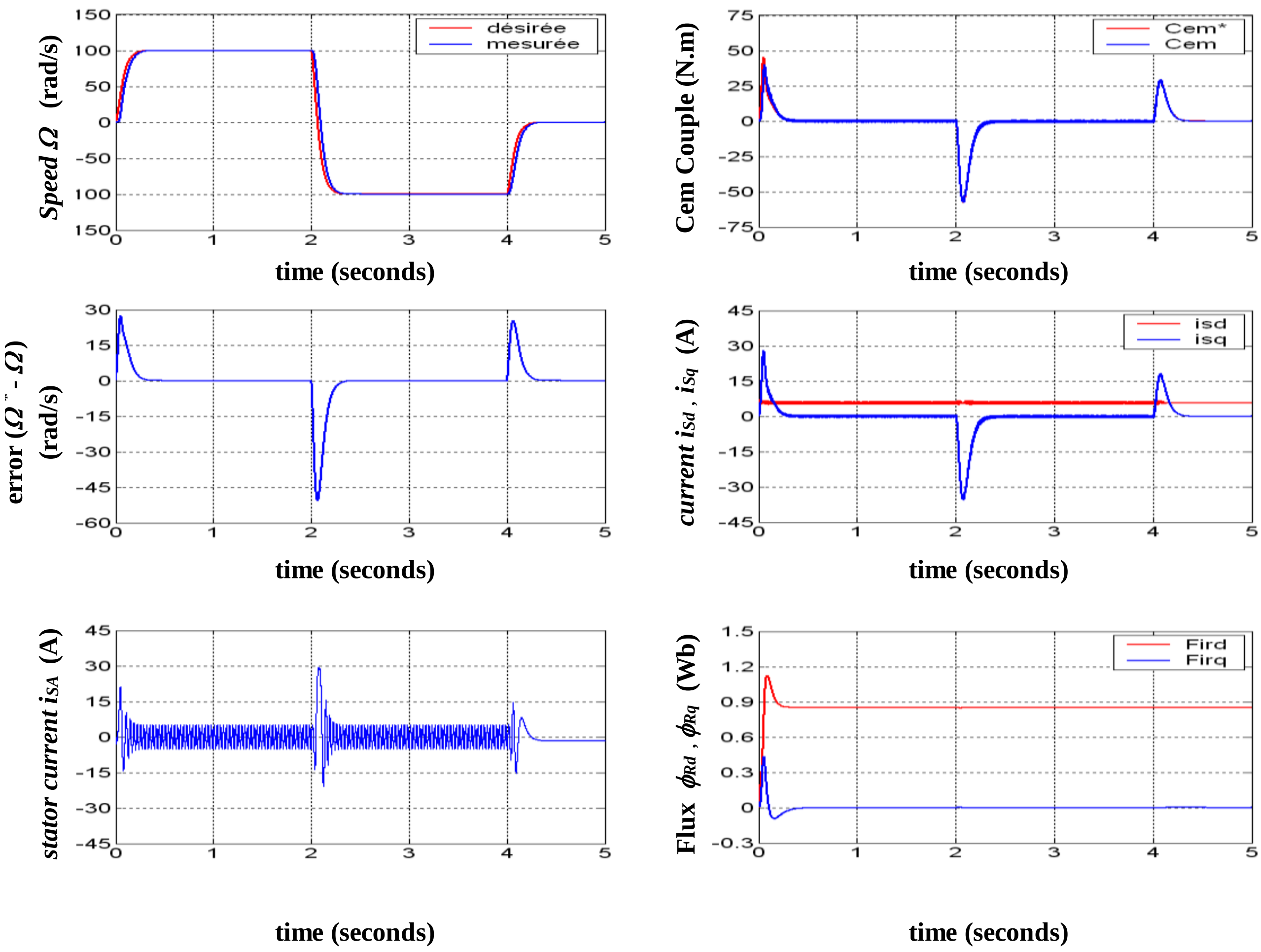

Figure 3. Response of the process to a speed step, followed by a reversal of the direction of rotation

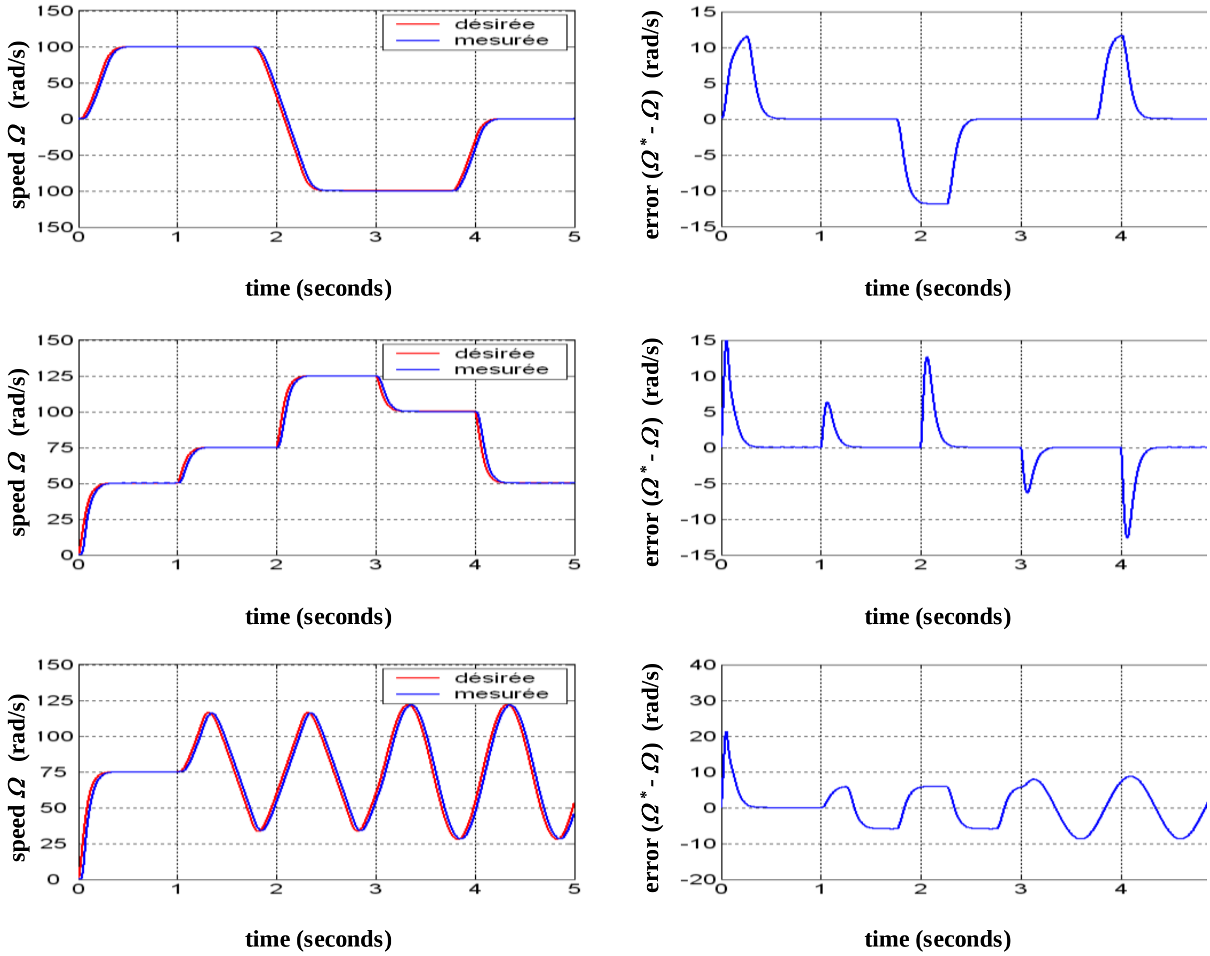

Figure 4. Process responses to different instructions

❖ Régulation tests

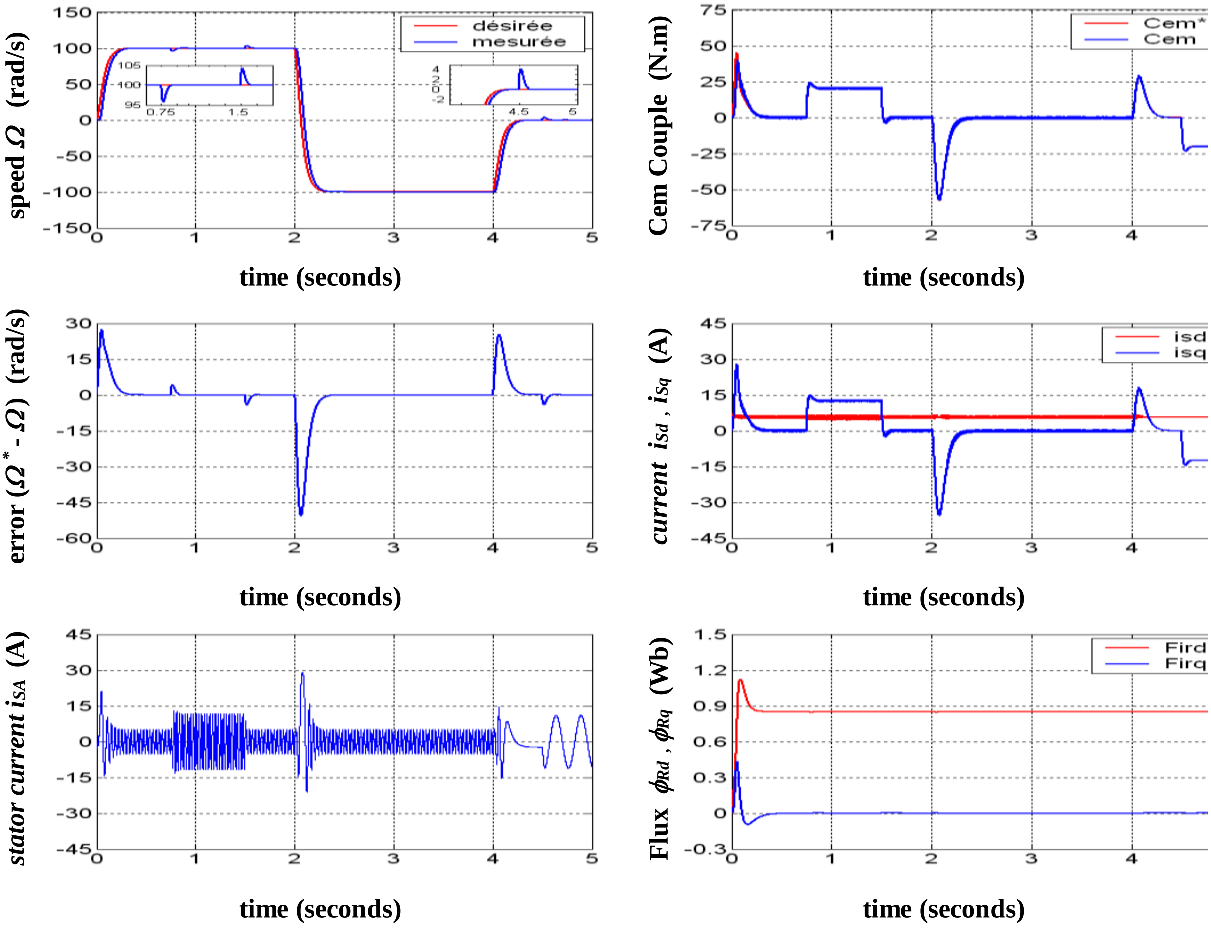

Figure 5. Response of the process to a speed step followed by a reversal of the direction of rotation with application and removal of a load torque

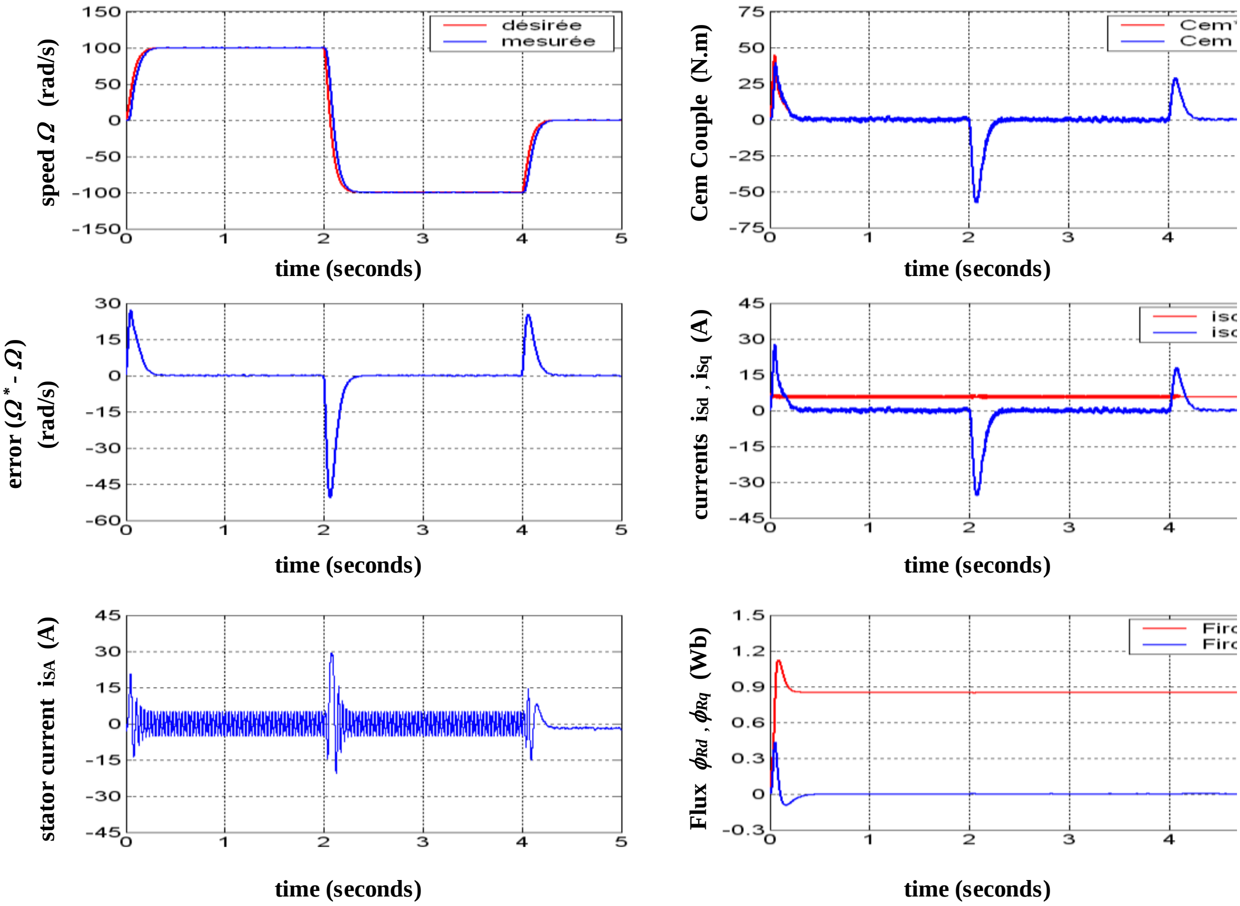

Figure 6. Response of the process to a speed step followed by a reversal of the direction of rotation with the application of a stochastic resistive torque

❖ Robustness tests with respect to parametric variations (moment of inertia)

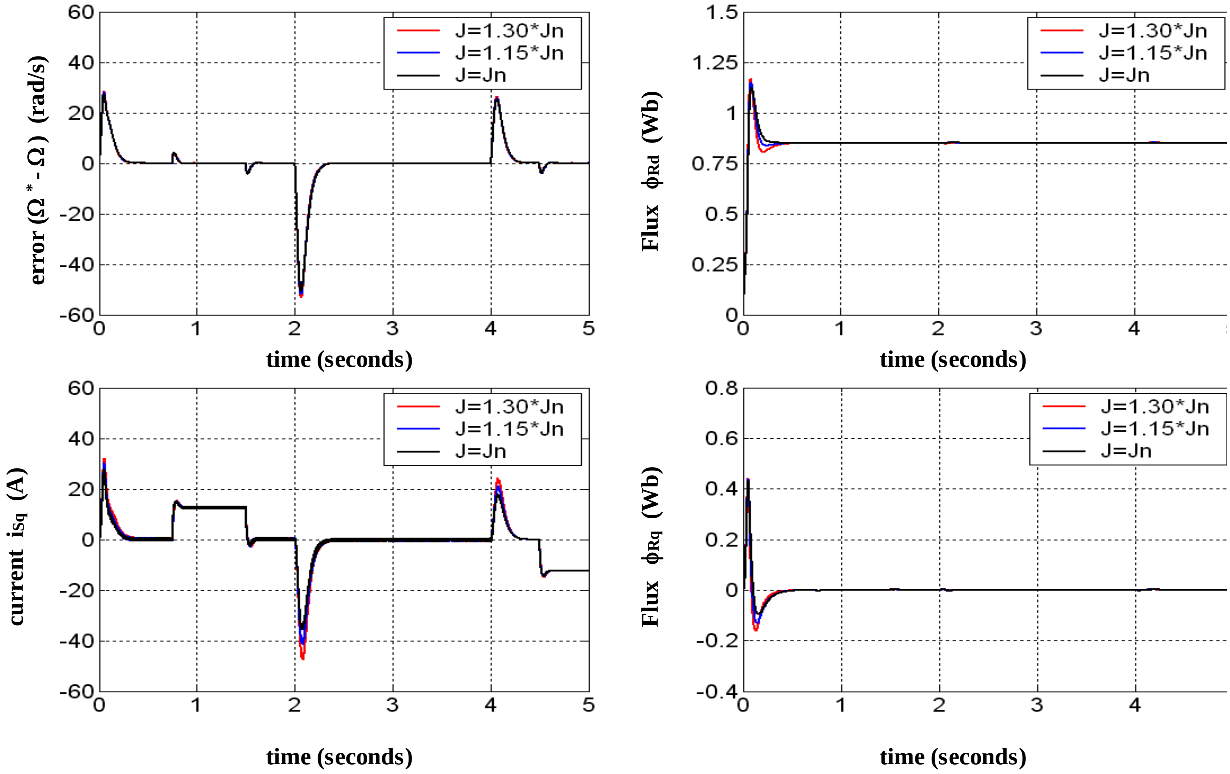

Figure 7. Response of the process to a speed step followed by a reversal of the direction of rotation, with application and removal of a load torque and variation of the moment

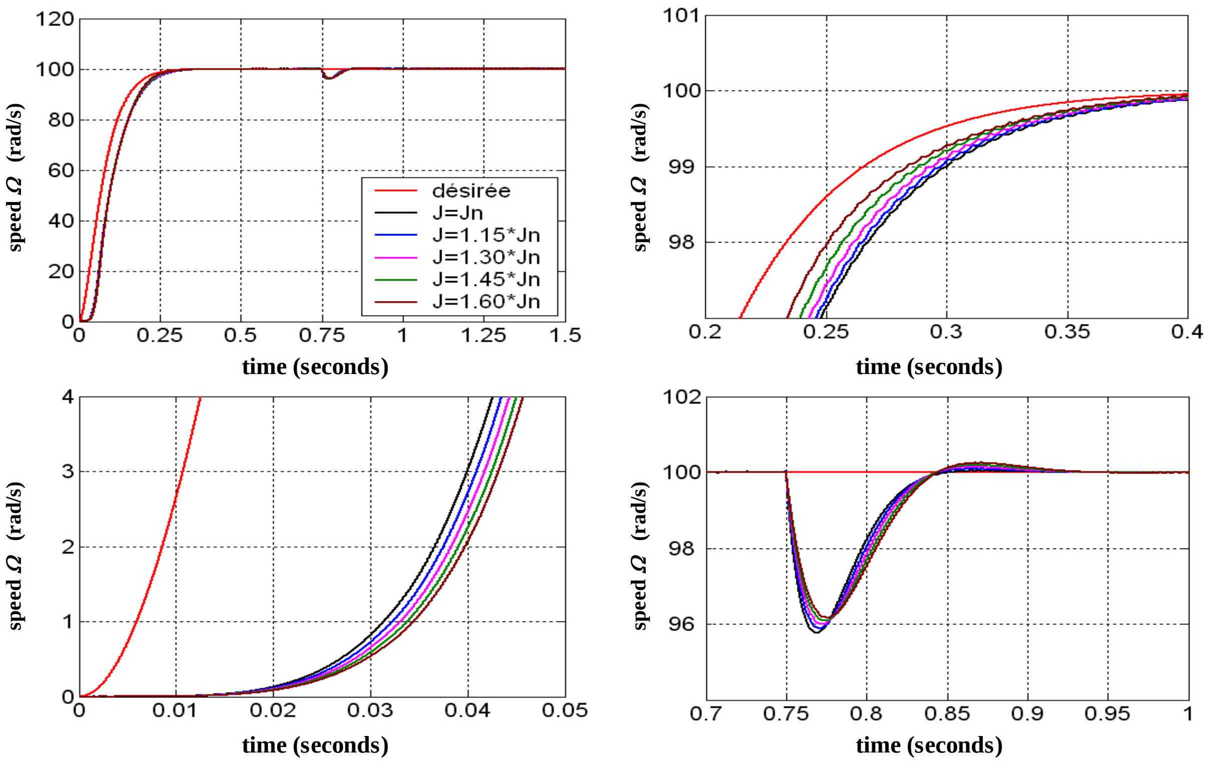

Figure 8. Response of the process to a speed step, with application of a load torque and variations in the moment of inertia from 0 to 1.6 times its nominal value

❖ Robustness tests against parametric variations (rotor resistance)

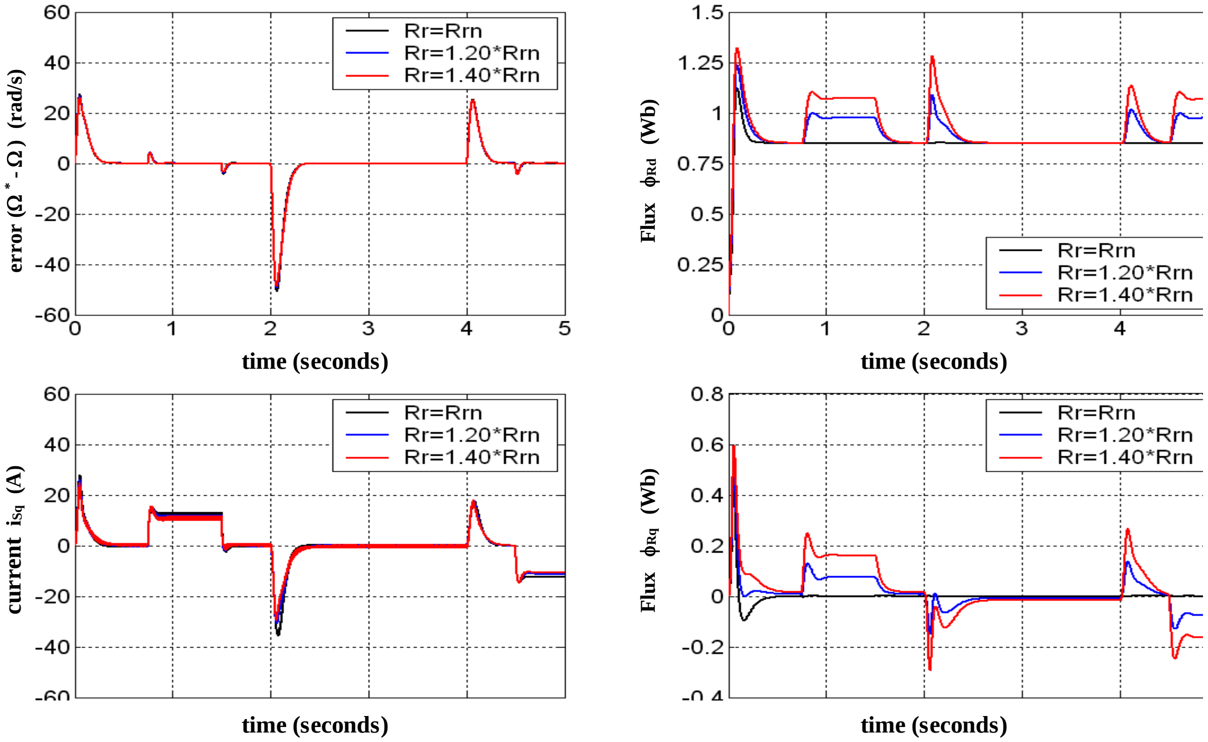

Figure 9. Response of the process to a speed step followed by a reversal of the direction of rotation, with application and removal of a load torque and variation of the rotor resistance

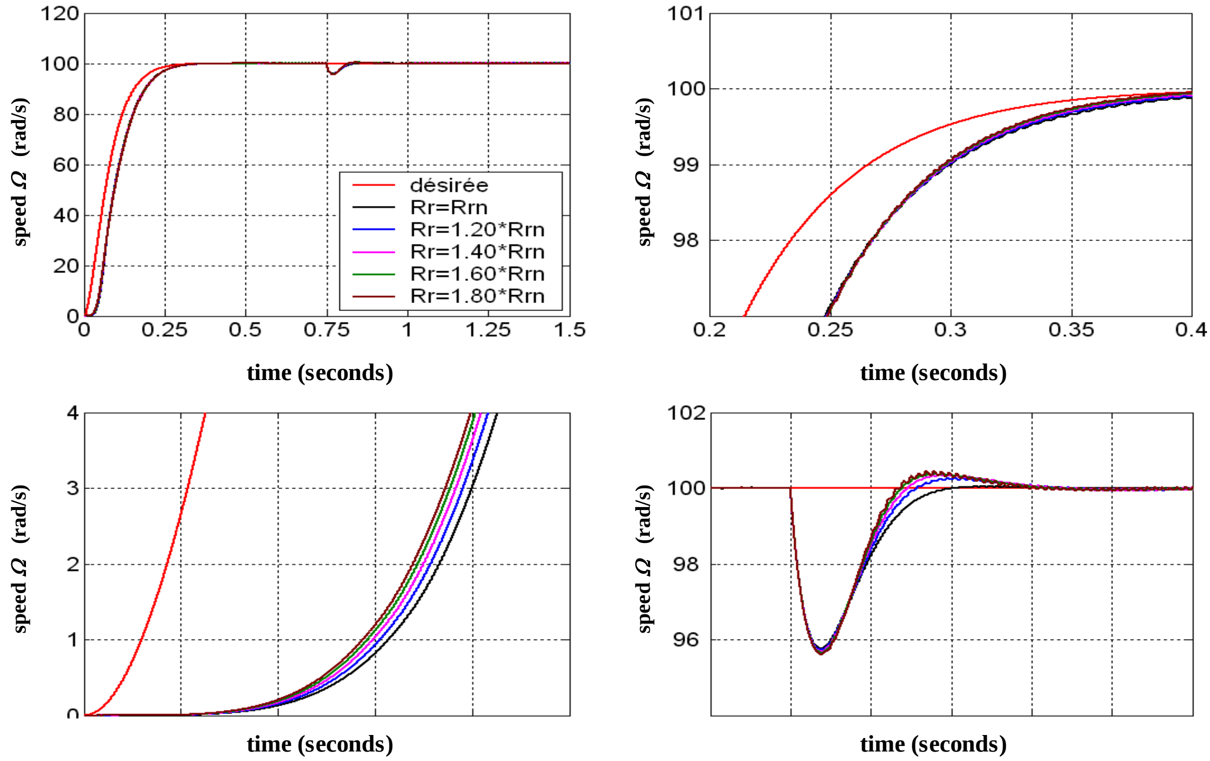

Figure 10. Response of the process to a speed step, with the application of a load torque and variations in rotor resistance from 0 to 1.8 times its nominal value

III. Control by Fuzzy Logic

III.1. PrincipE

The objective of logical control is to obtain an effective control law without having a precise model of the process to be ordered, but based on a qualitative linguistic description of the behaviour of the system.His approach to controlling a process does not deal with well-defined mathematical relationships, but exploits the knowledge and experience (expertise) acquired by the operator (expert).These are formulated using rules of conduct using symbolic vocabulary.Fuzzy logic tuning manipulates inferences with several fuzzy rules applied to linguistic variables.

The specificity of the fuzzy command lies in the fact that it is possible to model human reasoning. As for its interest, it appears clear for systems poorly known or difficult to describe. This simple type of control is easily adaptable to the operating conditions, with generally a low number of fuzzy rules to describe the system; the coordination of several control objectives is also possible (multivariable systems). A very interesting property also characterizes the control by fuzzy logic, indeed it is reputed as robust in the case of systems varying over time.moreover the regulators based on the concepts of fuzzy logic can have performances at least as good as the classical regulators, indeed S.Gallichet and demonstrate in [1], [4] .

There is a fuzzy regulator equivalent to any conventional regulator under the modal equivalence principle.

III.2. Structure of a fuzzy logic control

The structure of a command based on fuzzy logic is illustrated in Figure 11

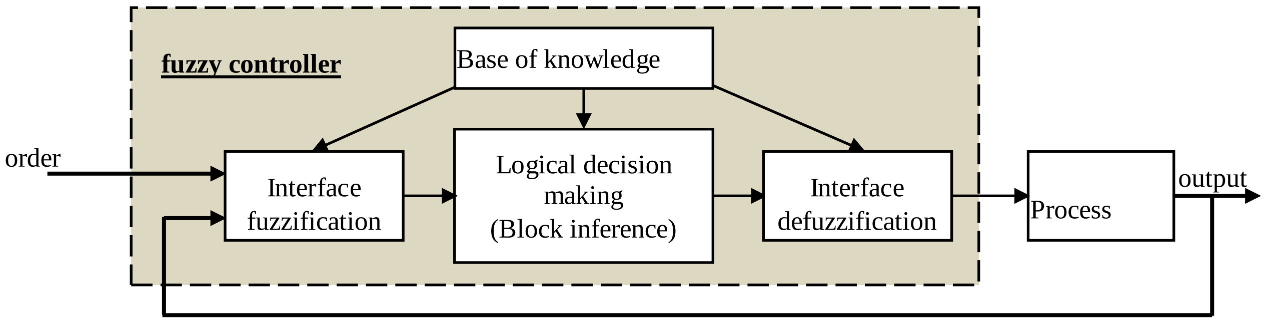

Figure 11. Basic structure of a fuzzy logic command

It consists of four blocks [8-9] :

- a fuzzification interface at the entrance,
- a knowledge base,
- decision making logic (or inference block),
- an output defuzzification interface

III.3. Synthesis of a fuzzy controller for speed control

III.3.1. Process Behaviour

It is essential to study the behaviour of the process to be ordered in order to obtain a description that will be the basis of the expertise.Nevertheless it is not necessary to know the mathematical model, but since it is available in our case, it will be used to test and modify the settings during the simulation phase.

Consider the typical response of a second-order or higher system, when applying a speed step, as illustrated in Figure 12

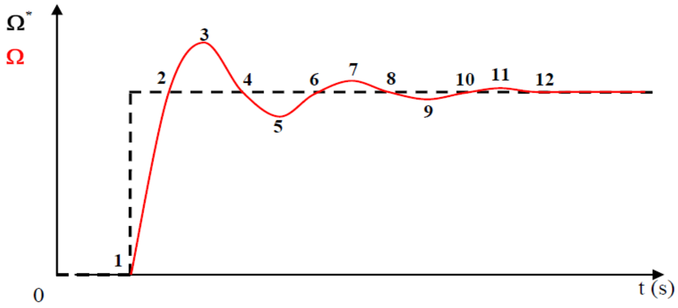

Figure 12.Typical response of a system to a speed step

By identifying the points of intersection between the set signal and the response, as well as the points where the response is maximum or minimal, the appropriate actions to be taken by the controller in order to achieve the minimum overrun and the lowest possible transitional regime can be deduced. Similarly, by observing the speed error and the variation of this error, noted respectively E and dE, Identical inferences can be obtained for variations in dU output that the controller must forward to the system using the phase plane trajectory (E,dE)[3] , [4].

- Structure of a fuzzy controller

Observation of the process shows that the significant quantities for the control are the speed error and the variation of this error.These two characteristic quantities, E and E, will therefore be adopted for the blurred corrector inputs.

As for its output, it represents the increment of the control signal to be applied to the process to be ordered, which corresponds to the value of the reference torque Cem*.

This configuration, similar to that of a conventional IP, is often referred to as fuzzy IP.
The speed loop configuration is illustrated in Figure 13 [2], [9] .

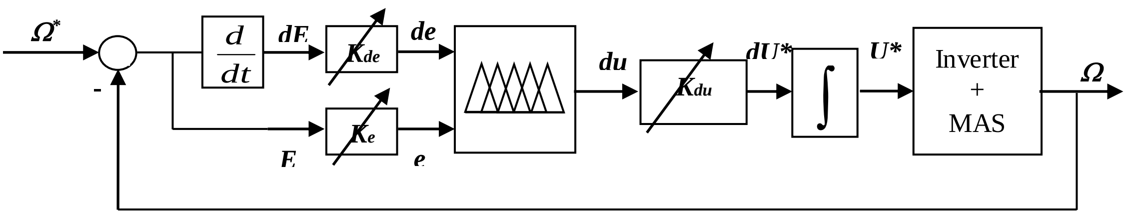

Figure 13. PI-fuzzy controller structure

The fuzzy controller inputs are determined at time k as follows:

$$E(k) = \Omega^{*}(k) - \Omega(k) \tag{9}$$

$$dE(k) = E(k) - E(k-1) \tag{10}$$

And the control signal is determined by the relation:

$$u^{*}(k) = u^{*}(k-1) + du^{*}(k) = Cem^{*}(k) \tag{11}$$

At each sampling period, the fuzzy controller issues a u*(k) command corresponding to its two inputs E(k) and dE(k).

III.3.2. type fuzzy controller MAMDANI

- Fuzzification

After several tests simulations we have chosen for the fuzzy controller a partition of the domain of discourse five subsets fuzzy and privileged triangular and trapezoidal forms for membership functions. These choices are illustrated in Figure 14

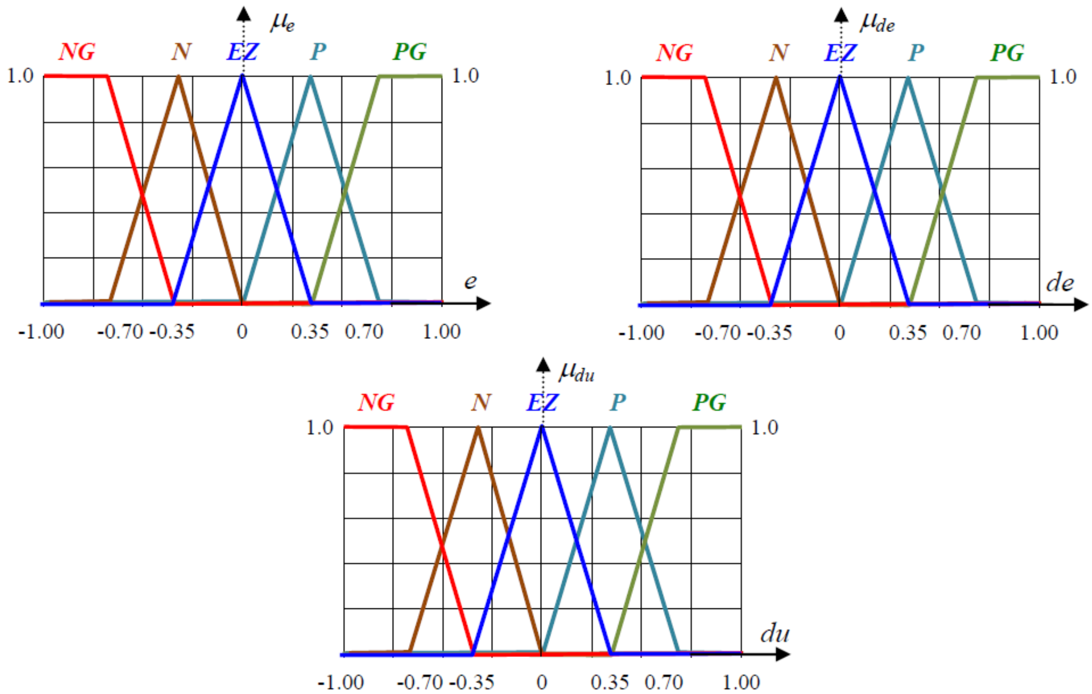

Figure 14 Membership functions for the input, e and output variables of the RLF5 controller

The shape of the membership functions and the partition of the selected universe of discourse enable a smooth response when the speed is close to the reference speed, then the subsets fuzzy EZ, N or P will be solicited. For cons, the fuzzy sets PG and NG will act in turn, when the speed error will be important to quickly close the gap.

- Digital processing inferences and defuzzification

For digital processing inferences concerning the fuzzy controller (RLF5) we have adopted for the "MAX-MIN" Mamdani method:

- AND operator: the minimum training,
- OR operator: formation of the maximum,
- THEN implication minimum training,
- Aggregation: training of the maximum.

The method of defuzzification retained is that the center of gravity.

- Rule base and inference matrix

The inference matrix for which we have opted forty nine rules, namely:

Table 2 inference Matrix

dE \ E	NG	N	EZ	P	PG
NG	NG	NG	N	N	EZ
N	NG	N	N	EZ	PG
EZ	NG	N	EZ	P	PG
P	NG	EZ	P	P	PG
PG	EZ	P	P	PG	PG

- Standardization gains

We set a goal to approach the PI controller defines speed in response to the previous chapter. Also for comparison purposes, we retain the same value of the rise time tr ≈ 50 ms for the process under a speed level and without load.
The above considerations and the many trials simulations, we have brought to the choice of normalization following gains:

$$K_e = 0.005 \qquad K_{de} = 12 \qquad K_{du} = 0.382$$

IV. Simulation Results

We conducted a series of simulations in order to study the behavior of RLF5 controller fitted to the set [+ asynchronous motor inverter], provides with indirect vector control.
The results for different simulation tests are exhibited in the figures:

- Figure 8 for regulatory testing.
- Figure 9 for the influence of variations in the rotor resistance.

The results show, for the fuzzy controller of RLF5 excellentesperformances, with a very good track beyond reference speed.

Note also that the orientation of the rotor flux is perfectly realized, more lecouple electromagnetic developed reproduced satisfactorily its reference Cem * cecimontrant the perfect fit of the fuzzy control to the vector control.

In terms of robustness vis-à-vis the parametric variations, examination of changes in responses of the rotational speed when the variations of rotor resistance, demonstrates the superiority of the fuzzy controller, and that despite these variations behavior tracking and control remain outstanding.

it is observed that changes in the rotor resistance affect the speed, but also on the orientation of the flow that is altered during the transient phases when disturbances.

It is noted in the change in resistance, an increase in the stator current isq quadrature, and an increased flux on the two axes d and q, where loss of decoupling and consequently lengthening of the durations of transient.

❖ **Test regulation**

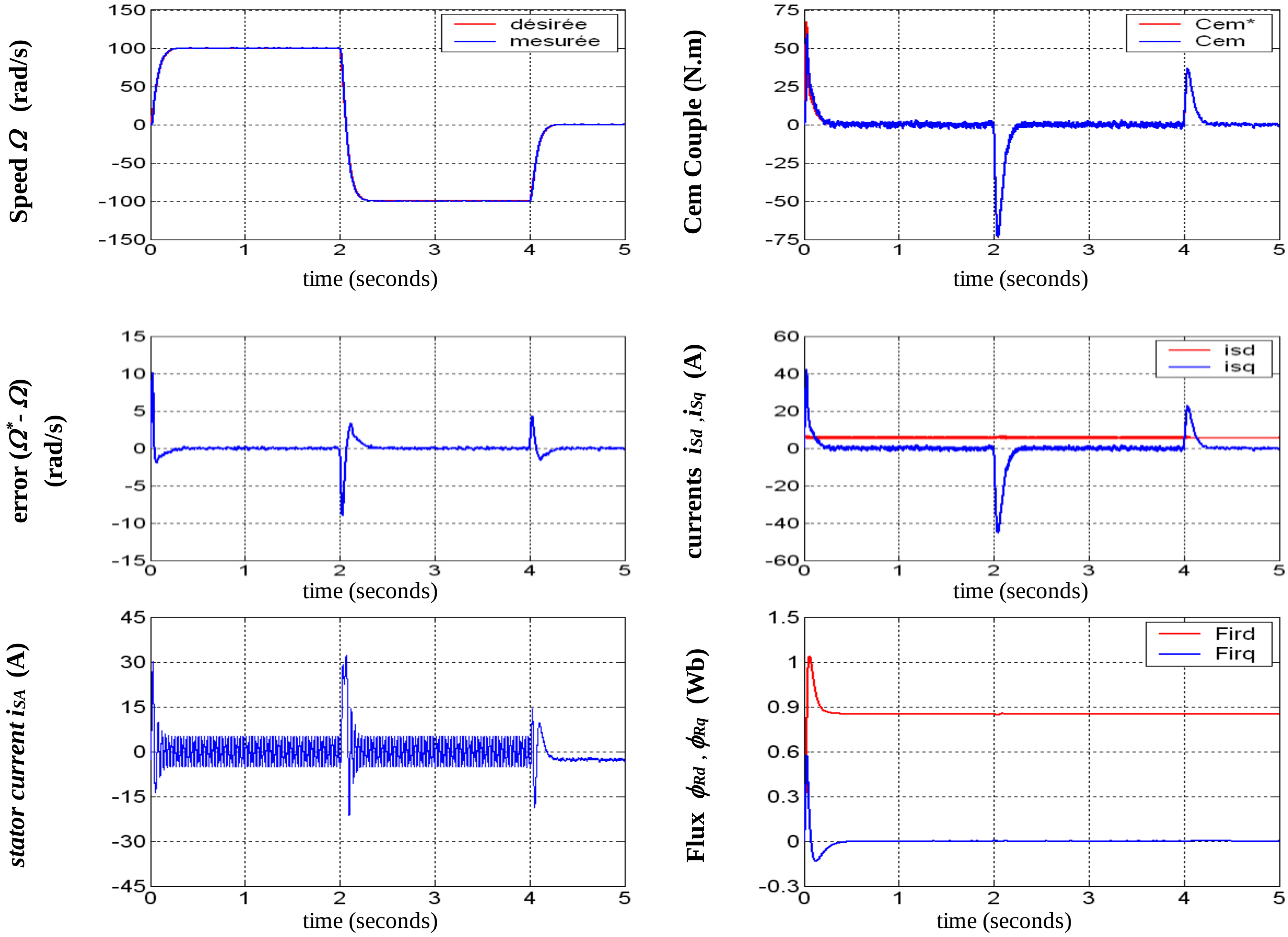

Figure15. Response method to a level of speed followed by a reversal of the direction of rotation with application of a torque resistant stochastic

- ❖ **Tests of robustness with respect to parameter variations (rotor resistance)**

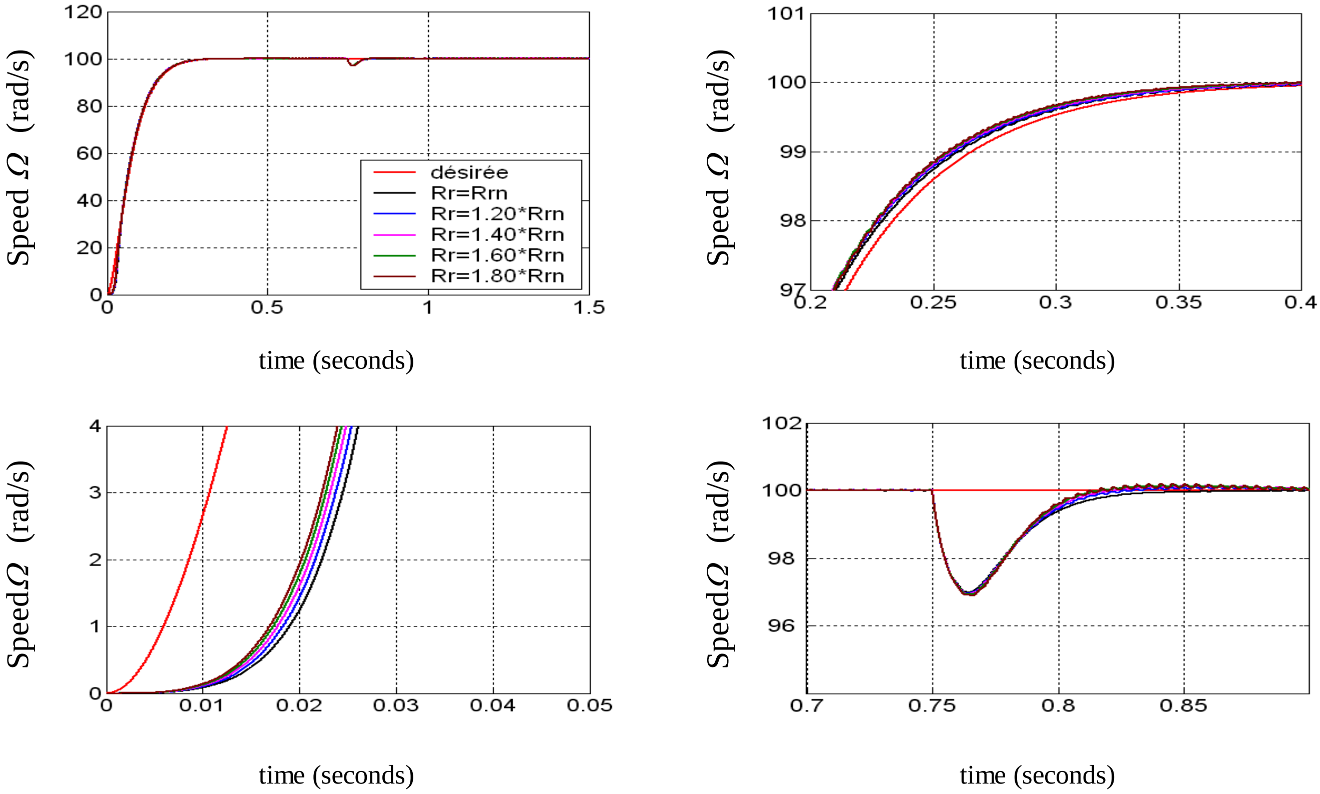

Figure 16 Response method to a speed step with the application of a torque load and variation of the rotor resistance from 0 to 1.8 times its nominal value

V. Conclusion

In this article we outlined the main theoretical concepts of fuzzy logic, and then completed the synthesis and evaluation of a fuzzy PI-type controller RLF5 five subsets. Simulation Tests showed satisfactory behavior of the fuzzy approach to regulation and tracking, its superiority over conventional PI controller was demonstrated by improved dynamics, better disturbance rejection and better robustness against deviations or variations in the rotor resistance.

Yet during simulations with strong variations of the parameters we note that the performance of the controller deteriorate too. What we are pushing to assert that the fuzzy controllers have vis-à-vis the performance of quite remarkable strength and this is owed to the adaptive nature that gives them a good distribution of the membership functions of the domain of discourse.

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